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AN EMPIRICAL MODEL FOR ATMOSPHERIC TRANSMISSION IN THE MID INFRARED SPECTRAL REGION

by

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Abstract

Taylor and Yates have measured atmospheric absorption in the infrared over long horizontal paths. They published thirteen spectra which covered four path lengths from 0.3 to 27.7 kilometers and seven water vapor concentrations from 0.10 to 2.3 pr cm/km. This report describes a method to fit their spectra to a model in the 3- to 5-micrometer interval. With this method, particulate scattering coefficients, band parameters of the Goody model for H₂O absorption and band parameters for the combined absorption of all other molecular species were extracted.

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1. Introduction

Considerable effort has been expended over the past several years to provide accurate atmospheric transmission models which are analytically tractable and, thereby, readily adaptable to digital computers. Anding [1] has provided a discussion of present computational models. The well-known experimental data of Taylor and Yates [2, 3] are widely used to compare various models. Since the models often disagree considerably in particular regions of the spectrum, it was felt desirable to fit the data of Taylor and Yates to a band model in a spectral interval of immediate interest to several working groups.

This report discusses a method to derive a set of band parameters from the measured transmission data of Taylor and Yates in the 3- to 5-micrometer spectral interval. Taylor and Yates measured the extinction of light which had traversed various distances from a carbon arc searchlamp to a monochromatic receiver over land, across Chesapeake Bay, over water parallel to the bay shoreline, and between two Hawaiian mountain tops at 10,000 feet.

Two effects cause attenuation of the light — scattering by small water droplets and other particles, and absorption by certain molecular species, such as H_2O , CO_2 , N_2O , NH_4 , and CO . The overall transmission for a given wavelength is

$$T(\lambda) = T_a(\lambda) T_s(\lambda) ,$$

where a and s refer to absorption and scattering, respectively.

Since the amount of aerosol was not recorded and the aerosol cross sections vary with meteorological conditions, to separate T_a and T_s would be impossible were it not for spectral differences between the two. Lines accent the T_a spectrum, but T_s is only weakly wavelength dependent. Sharp variations in the spectrum can be attributed to absorption, and overall attenuation to scattering. Because the absorption by many overlapping spectral lines can be mistaken for scattering, the separation of T_a and T_s will be slightly ambiguous.

Since two parameters are varied in the Taylor and Yates data — the amount of water vapor in the path and the length of the path — one can expect to separate the molecular absorption into that of water vapor and that of all constituents of constant concentration. Unavoidably, the absorption by CO_2 , N_2O , CH_4 , and CO is combined, the sum of which will be attributed to a single species, XO_2 . The amount of XO_2 was chosen to be 32 atm cm/km, which is the average concentration of CO_2 .

The Goody model [4] was selected for its computational simplicity. It is described by the expression

$$T_a = \exp\left\{-(S/\ell)\ell\left[1 + 2(S/2\pi\alpha)P\ell\right]^{1/2}\right\}.$$

In this model the spectral lines are assumed to be located randomly in frequency with a mean spacing d , half widths α , and strengths exponentially distributed with a mean intensity S . The amount of absorbing material is ℓ , and P is the total pressure in atmospheres. Temperature effects, which would introduce extra parameters into the model, were not considered. This model is physically applicable for molecules with low symmetry. A model with a uniform line spacing describes linear molecules such as CO_2 and N_2O more accurately. All models predict $T_a \propto \ell$ for small ℓ and $T_a \propto \sqrt{\ell}$ for large ℓ . If the data are limited to one of these asymptotic regions, the curves of growth can be described by the Goody model as well as any physically accurate model. The band parameters are not uniformly accurate over the entire band. In regions of weak H_2O absorption, it is possible to determine the XO_2 parameters precisely, but when H_2O absorption masks XO_2 absorption, to deduce XO_2 parameters, albeit roughly, is difficult even though its absorption may be as strong as in the former case.

The goal of this empirical approach is to separate the transmission into three components, $T = T_s T_{\text{H}_2\text{O}} T_{\text{XO}_2}$. The method to extract T_a is discussed in section 2. The algorithm to separate $T_{\text{H}_2\text{O}}$ from T_{CO_2} is described in section 3. The least information that this empirical approach yields is a set of parameters that reproduce the Taylor and Yates spectra. Reproducing the fitted data is not difficult since an error in $T_{\text{H}_2\text{O}}$ can be corrected accidentally by an opposite error in T_{XO_2} . At best the method can determine T_s , $T_{\text{H}_2\text{O}}$, and T_{XO_2} separately. If known N_2O absorption appears as an increase in the XO_2 parameters and not in the H_2O parameters, the method is successful.

2. Particulate Scattering

A scattering coefficient k , defined by $T_s = \exp(-k\ell)$ where ℓ is the path length, was found by the procedure described below. If a wavelength λ_0 for which there was no molecular absorption existed, then the scattering could be found by $T_s = T/T_a = T(\lambda_0)/1 = T(\lambda_0)$. For the short path lengths this procedure is possible. However, $T_a \neq 1$ for all wavelengths of the Taylor and Yates spectra over the longer path lengths, and a different procedure must be used.

From the fine resolution spectra of Howard [5], one finds only extremely weak lines in the interval 3.96 to 4.01 micrometers. In this interval, the transmission, which is attenuated by the wings of CO₂, has the form $T_a = \exp(-aPl_{XO_2})$.

The coefficient a was derived from spectra of short path lengths for which $T_s = T(\lambda_0)$. The unknown scattering was found by $T_s = T/T_a = T \exp(aPl_{XO_2})$.

This method relies on a single spectral point to derive the scattering for the entire spectrum; a global procedure is more reliable. A band absorption model was calculated with the set $\{T_s\}$. A new set $\{T'_s\}$ was calculated by

$$T'_s = \frac{1}{N} \sum_{i=1}^N T(\lambda_i) / T_a(\lambda_i), \text{ where } i \text{ indexes the spectral points and } T_a(\lambda_i) \text{ was}$$

calculated by the model. The final band absorption model was calculated with $\{T'_s\}$. Table I shows $\{T_s\}$ and $\{T'_s\}$. Since the absorption is temperature dependent, neglecting temperature effects in the model would introduce some scatter in the values of T_s . An attempt to improve the sums of errors of the fit by allowing a wavelength dependent k yielded slopes in the interval ± 0.02 k/micrometer, but failed to improve the error enough to indicate the slopes were real.

TABLE I. SCATTERING COEFFICIENTS

Path Length (km)	H ₂ O (pr cm)	T_s	T'_s	k (km ⁻¹)
0.3	0.1	1.00*	1.00*	0.00*
0.3	0.6	1.00*	1.00*	0.00*
5.5	1.4	0.79	0.79	0.043
5.5	2.2	0.75	0.79	0.043
5.5	4.2	1.00	0.97	0.005
5.5	9.4	0.97	0.93	0.014
16	5.2	0.58	0.63	0.028
16	6.7	0.67	0.67	0.025
16	15	0.85	0.84	0.011
16	28	0.63	0.66	0.025
16	37	0.95	0.91	0.006
27	10	0.60	0.55	0.022
27	20	0.69	0.70	0.013

*By definition.

3. Molecular Absorption

The Goody model can be rewritten

$$-\log T_a = \left(\frac{a}{Pl_{H_2O}} + \frac{b}{l^2_{H_2O}} \right)^{-1/2} + \left(\frac{c}{Pl_{XO_2}} + \frac{d}{l^2_{XO_2}} \right)^{-1/2}. \quad (1)$$

In regions of no XO_2 absorption, c and d should be zero.* However, a fit would likely give spurious non-zero c and d coefficients. Contractions of the model must be considered. Let $(a, b, c, 0)$ denote the model

$$-\log T_a = \left(\frac{a}{Pl_{H_2O}} + \frac{b}{l^2_{H_2O}} \right)^{-1/2} + \left(\frac{c}{Pl_{XO_2}} \right)^{-1/2}.$$

The notation $(a, b, 0, 0)$, etc., is defined similarly.

An algorithm was devised to make a fit with the optimal number of coefficients. Hopefully, the algorithm could decide to use $(a, b, 0, 0)$ when XO_2 absorption was negligible. First, the best one-coefficient model was chosen from the models $(a, 0, 0, 0)$, $(0, b, 0, 0)$, $(0, 0, c, 0)$, and $(0, 0, 0, d)$. Suppose $(0, b, 0, 0)$ had the least sum of squares of errors. The best two-coefficient model was chosen from all possible combinations of two coefficients. Assume it was $(a, 0, c, 0)$. From $(a, b, c, 0)$ and $(a, 0, c, d)$, the best three-coefficient model was chosen, say $(a, 0, c, d)$. Intuitive criteria picked the optimal model from the three best models; in this example, $(0, b, 0, 0)$, $(a, 0, c, 0)$, and $(a, 0, c, d)$. Since the three-coefficient model would mirror the data most precisely — fortuitously in most cases — the least errors condition is insufficient to reject accidental fits. The Goody model precludes negative coefficients because $-\log T_a = (Pl/a)^{1/2}$ when l is large and $-\log T_a = (l^2/b)^{1/2}$ when l is small. The first test utilizes this fact. Criterion 1 is to reject models with negative coefficients. However, spurious models with positive coefficients would pass criterion 1. In most cases the fortuitous model improves the error only slightly over the true model of fewer coefficients. Criterion 2, to minimize $\Sigma(\text{errors})^2 / (\text{No. of data points} - \text{No. of coefficients})$, would weed out the unwanted models. Perhaps statistical theory requires some other factor, but this question was not explored.

*The number $1/0$ is interpreted to be ∞ so that $c = d = 0$ instead of $c = d = \infty$ indicates absence of XO_2 .

In the CO₂ wings the model was replaced by

$$-\log T_a = P \ell_{\text{XO}_2} / g^{1/2} \quad (2)$$

The pressure factor is P in the Lorentz theory of line profile, and Winters, Silverman, and Benedict [6] have confirmed it for the far wings of the 4.3-micrometer CO₂ band.

Since the distance between the source and detector was measured, the perfect gas correction for temperature and pressure was made to reduce ℓ_{XO_2} amounts to a standard sea level reference, by using

$$\ell_{\text{XO}_2}(T, P) / \ell_{\text{XO}_2}(T_0, P_0) = (P/P_0) (T_0/T)$$

All fits were done by the least squares method, to minimize errors in $-\log T_a$. Datum was not used if $T_a \geq 0.98$ or $T_a \leq 0.05$. The average error was $\langle (\Delta T_a / T_a)^2 \rangle = 0.02$.

4. Calculated Band Parameters

The band parameters, which were calculated with the scattering transmission set $\{T_s\}$, are listed in Table II. The wavelengths, which are meant to identify spectral features such as maxima and minima, have errors no larger than 0.005 micron. The model is capable of reproducing the Taylor and Yates spectra sufficiently. Figure 1 compares the fit the model generated and one Taylor and Yates spectrum. These coefficients should not be extrapolated beyond the limits (0.3 km, 17 km) at sea level and (0.1 pr cm H₂O, 37 pr cm H₂O).

To decide if the algorithm separated XO₂ from H₂O, one transmission curve was compared to the laboratory data of Howard, Burch, and Williams [7, 8] for individual species. Since the conditions of their artificial atmosphere did not match those of the Taylor and Yates data, comparisons should decide qualitatively how well XO₂ was separated from H₂O, and precise agreement is not expected. In Figure 2, $-\log T_{\text{H}_2\text{O}}$ was plotted for

$\ell_{\text{H}_2\text{O}} = 9.4$ pr cm, and $-\log T_{\text{XO}_2}$ for $\ell_{\text{XO}_2} = 176$ atm cm. The latter, the lower curve, was shifted down by a factor of 10 to offset the two curves. Superimposed on this graph are several transmission curves of Howard, Burch, and Williams. From 3.0 to 3.5 micrometers, H₂O is the dominant absorber. In

the $2\nu_2$ band at 3.2 micrometers, the CH_4 band center barely appears against strong H_2O absorption, but the band edge is seen clearly where H_2O absorption is weaker. From 3.5 to 3.8 micrometers the HDO band is a prominent feature in the H_2O curve. Most HDO peaks were matched with HDO line clusters of Howard [5]. The XO_2 absorption, in this interval, may be attributed to CH_4 lines. From 3.8 to 4.2 micrometers there are two N_2O bands and the featureless CO_2 wings. The N_2O and CO_2 bands dominate from 4.36 to 4.6 microns. From 4.6 to 5.0 microns most of the H_2O peaks were identified with clusters of H_2O lines in the solar spectrum of Shaw, Chapman, Howard, and Oxholm [9]. Half of the 4.8-micrometer CO_2 band was masked by stronger H_2O absorption. The CO band was not resolved clearly.

A computer program that computes transmission spectra with the band model of Table II is listed in the appendix.

TABLE II. BAND PARAMETERS

Wavelength (μm)	$b^{1/2}$ (pr cm)	$a^{1/2}$ (pr cm-atm) $^{1/2}$	$d^{1/2}$ (atm cm) $*g^{1/2}$ (atm cm-atm) $^{1/2}$	$c^{1/2}$ (atm cm-atm) $^{1/2}$
3.000		8.936E-01		
3.010	7.415E-01	7.694E-01		
3.020		8.273E-01		
3.030		9.229E-01		
3.040		7.297E-01		
3.050	2.624E-01	5.131E-01		
3.060	3.741E-01	6.899E-01		
3.070	8.916E-01			
3.080		8.591E-01		
3.090	7.058E-01			
3.100	7.485E-01			
3.110	2.451E-01	4.975E-01		
3.120	6.864E-01	8.095E-01		
3.130	8.164E-01	9.472E-01		
3.140		8.712E-01		
3.160	3.497E-00	1.464E-00		
3.170	2.232E-00	1.412E-00		
3.200	1.106E-01	3.825E-01		
3.216	2.199E-01	4.614E-01		
3.223	1.587E-01	4.460E-01		
3.230	4.634E-01	8.925E-01		
3.240		7.676E-01		
3.250	4.410E-01	1.105E-00		
3.260		9.715E-01	3.406E+02	
3.270	7.413E-00			4.495E+01
3.290		7.172E-01		
3.300	5.687E-01	7.621E-01		
3.310		8.914E-01		1.602E+01
3.327	1.140E-00	1.519E-00		
3.333		1.166E-00		
3.340	9.123E-01	1.162E-00		
3.350	8.507E-01	1.022E-00		
3.370		1.818E-00		
3.380		1.866E-00		
3.400	2.281E+01			6.063E+01
3.402		2.526E-00		1.187E+01
3.420		5.727E-00		
3.427		5.092E-00		
3.433		5.083E-00		
3.440	3.177E+01			8.221E+01
3.445		5.906E-00		
3.450	3.097E+01			9.850E+01
3.460	4.831E+01			1.362E+02
3.470	4.243E+01			1.311E+02
3.490	4.250E+01			2.695E+02
3.500	3.867E+01			2.199E+02
3.514	5.068E+01			2.344E+02

TABLE II. BAND PARAMETERS (Continued)

Wavelength (μm)	$b^{1/2}$ (pr cm)	$a^{1/2}$ (pr cm-atm) $^{1/2}$	$d^{1/2}$ (atm cm) $*g^{1/2}$ (atm cm-atm) $^{1/2}$	$c^{1/2}$ (atm cm-atm) $^{1/2}$
3.525	4.922E+01		2.529E+03	
3.535	4.382E+01		3.068E+03	
3.540	1.526E+01	3.526E-00		1.768E+02
3.550	1.737E+01	3.391E-00		2.777E+02
3.555	1.203E+01	3.470E-00		
3.560	2.257E+01	6.435E-00		4.338E+02
3.570	1.235E+01	4.347E-00		6.263E+02
3.580	2.420E+01	6.051E-00		1.832E+02
3.585	2.557E+01			1.533E+02
3.600	5.271E+01			2.563E+02
3.615	3.396E+01			1.75E+02
3.625	7.459E+01			3.456E+02
3.635	4.038E+01			3.198E+02
3.645	9.098E+01			
3.650	4.293E+01			
3.655	4.945E+01			
3.670	3.250E-00	2.409E-00		
3.700	9.463E+01			
3.710	3.471E+01			
3.720	7.476E+01			
3.730	3.111E+01			3.799E+02
3.745	6.232E+01			
3.755	2.450E+01			
3.770	4.970E+01			4.750E+02
3.790		5.850E-00		
3.800	1.233E+02		7.110E+03	
3.810	1.535E+01	3.932E-00		4.816E+02
3.820	8.637E+01			
3.830	3.307E+01		3.424E+03	
3.840	1.051E+02		3.717E+03	
3.860	4.636E+01		2.112E+03	
3.870	1.032E+02		1.681E+03	
3.880	8.079E+01		7.358E+02	2.965E+01
3.910		3.727E+01	2.646E+03	
3.930	6.839E+01		1.152E+03	5.382E+01
3.940	1.559E+02		1.397E+03	7.772E+01
3.950	1.812E+02		1.092E+03	8.354E+01
3.960*			2.069E+03	
4.000*			1.413E+03	
4.050*			6.200E+02	
4.060*			5.699E+02	
4.100*			3.562E+02	
4.140*			2.139E+02	
4.150*			1.866E+02	
4.160*			1.798E+02	
4.180			9.545E+01	
4.190				
4.350				

*Model of Equation (2), otherwise model of Equation (1).

TABLE II. BAND PARAMETERS (Concluded)

Wavelength (μm)	$b^{1/2}$ (pr cm)	$a^{1/2}(\text{pr cm-atm})^{1/2}$	$d^{1/2}$ (atm cm) $*g^{1/2}(\text{atm cm-atm})^{1/2}$	$c^{1/2}(\text{atm cm-atm})^{1/2}$
4.377			6.101E 00	
4.380			5.356E 00	
4.450			1.499E 00	
4.490	2.567E+01		1.173E+02	
4.500	1.285E+01		7.415E+01	
4.520	1.060E+01		8.115E+01	
4.530	6.491E-00		9.816E+01	
4.554	3.266E+01		9.191E+01	8.626E-00
4.560	2.577E+01		7.249E+01	9.066E-00
4.587	2.544E+01			3.091E+01
4.595	2.266E+01			2.676E+01
4.605	2.397E+01			5.136E+01
4.615		2.113E-00		
4.630	1.496E+01			1.173E+02
4.637	1.378E+01			7.234E+01
4.643	1.355E+01			1.490E+02
4.650	2.121E-00	2.041E-00		
4.660	1.359E+01			
4.670		1.406E-00		
4.680	1.684E+01			
4.690	1.477E+01			2.027E+02
4.700	1.343E-00	1.834E-00		
4.715	1.348E+01			1.672E+02
4.720		1.633E-00		
4.730	1.363E+01			
4.740	1.537E-00	2.094E-00		
4.745	1.108E+01	1.625E-00		1.984E+02
4.755	3.596E-00	1.630E-00		4.784E+02
4.760	3.270E-00	1.711E-00		
4.780		1.032E-00		
4.790	9.529E-00			1.447E+02
4.800	5.365E-00			1.385E+01
4.810	4.715E-00			3.338E+01
4.820	8.377E-00			4.189E+01
4.830		6.575E-01		
4.840	7.575E-01	9.834E-01		1.022E+02
4.855	2.674E-00	1.470E-00		
4.860	2.781E-00	1.306E-00		
4.870	2.909E-00	1.319E-00		
4.890		6.757E-01		
4.900	4.392E-00			
4.920	7.777E-00			
4.930		1.116E-00		
4.940	7.341E-01	7.321E-01		
4.955	1.871E-01			
4.965	2.903E-00			
4.975		7.618E-01		
4.990	4.568E-00			
5.000	3.638E-01	7.453E-01		

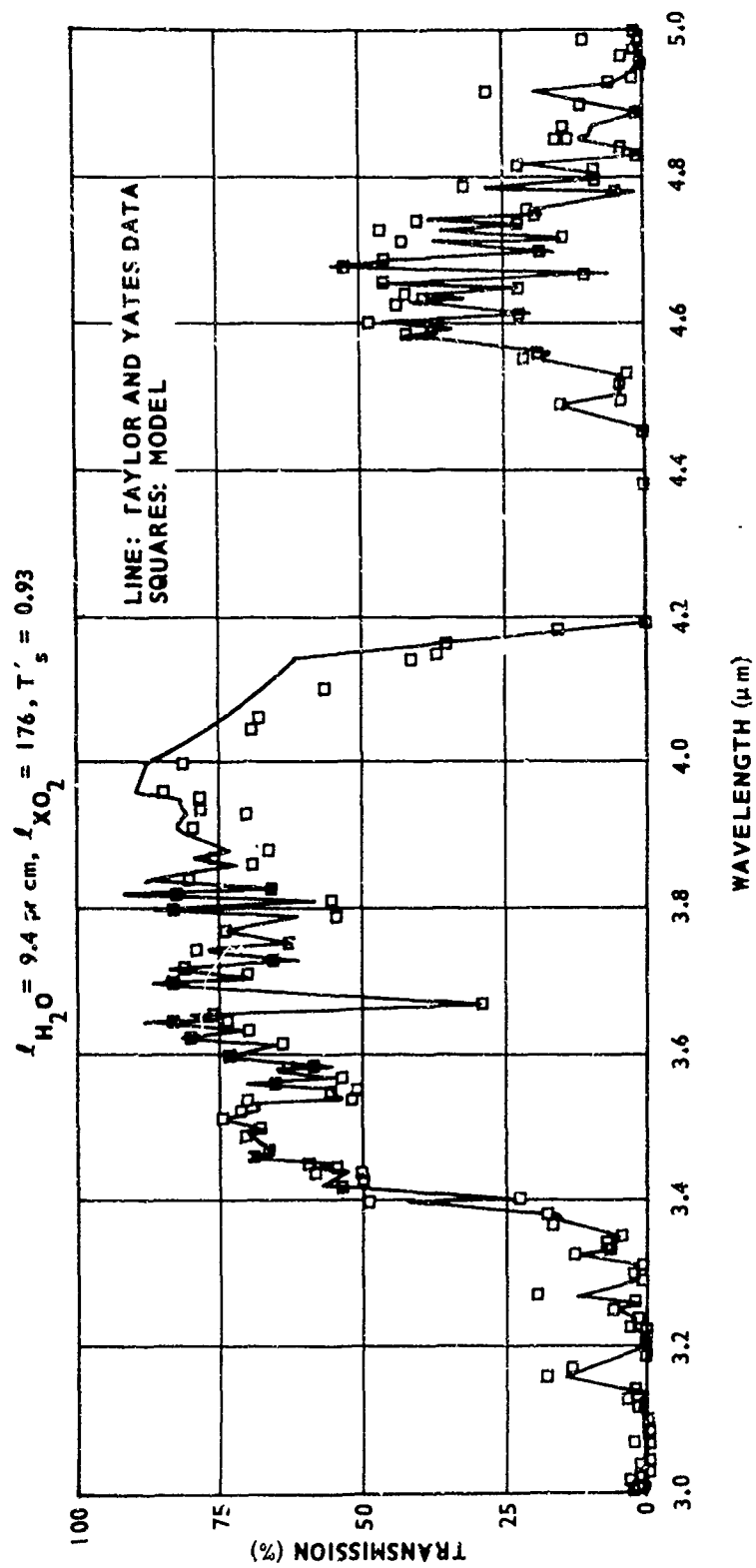


FIGURE 1. COMPARISON BETWEEN MODEL AND TAYLOR AND YATES DATA

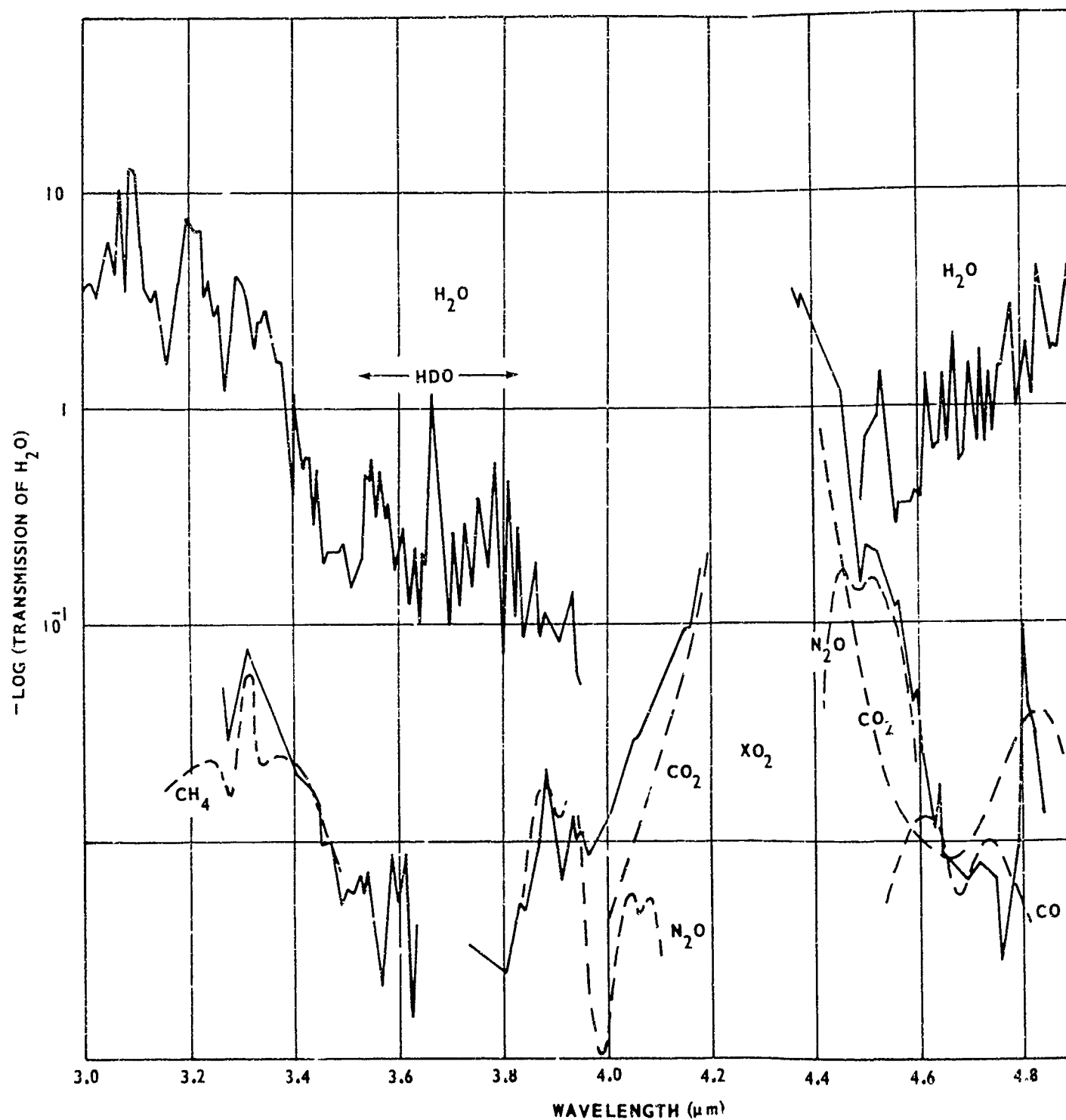
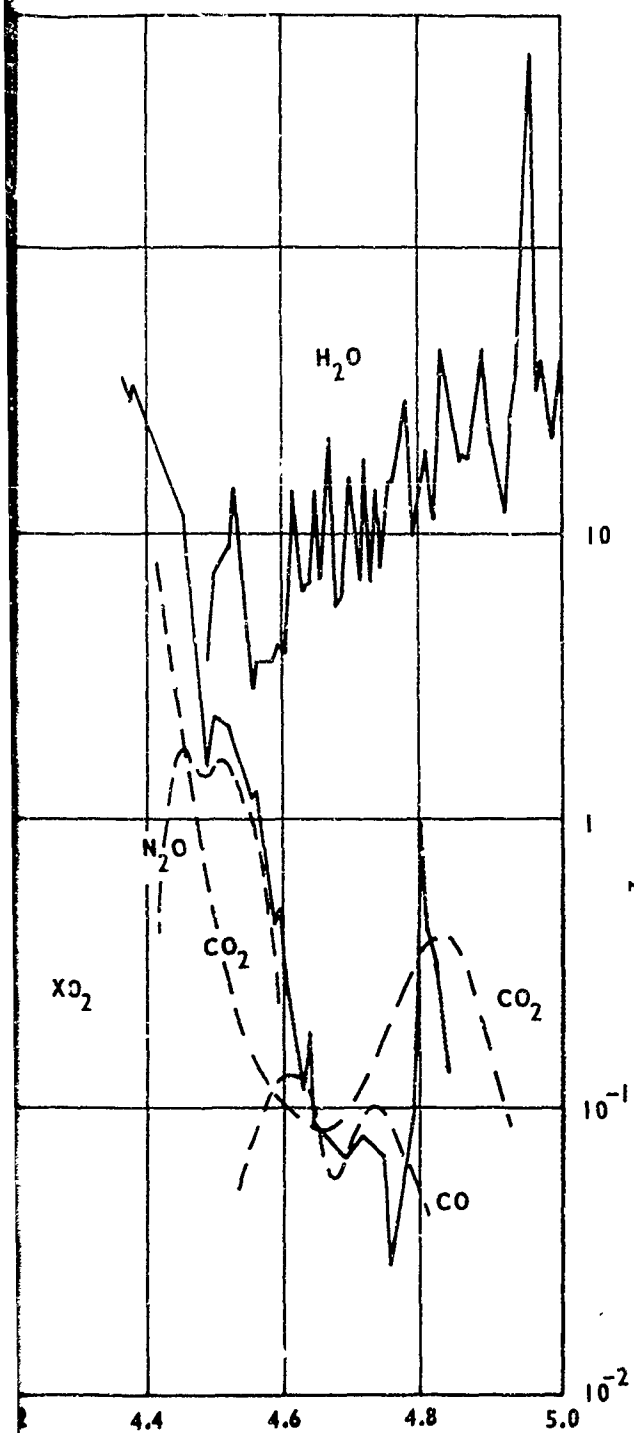


FIGURE 2. COMPARISON BETWEEN MODEL AND LABORATORY DATA



UPPER CURVE: $-\text{LOG } T_{\text{H}_2\text{O}}$ FOR
 $\ell_{\text{H}_2\text{O}} = 9.4 \text{ pr cm}$

LOWER CURVE: $-\text{LOG } T_{\text{XO}_2}$ FOR
 $\ell_{\text{XO}_2} = 176 \text{ atm cm}$

DOTTED CURVES: LABORATORY DATA
 FROM REF 7 AND 8

BETWEEN MODEL AND LABORATORY DATA

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Appendix
Fortran IV Program to Calculate Transmission Spectra

The Fortran IV program listed here computes transmission spectra with the band parameters of Table II. The necessary input data are: a) the amount of water in the path in precipitable centimeters, b) the sea level path length in kilometers, c) the pressure in atmospheres, and d) the amount of scattering. A sample set of input and output is shown for $f_{\text{H}_2\text{O}} = 34.5$ pr cm, path length 15 km, 1 atm pressure and $T_s = 1$. To calculate several spectra at a time, additional input cards are inserted, one for each spectrum. This program was written for the IBM 7094 computer.

***** SOURCE PROGRAM AND SAMPLE INPUT *****

```

$IBFTC HCLEB
  DIMENSION W(144),COEF(4,144),T(144),I(4),A(4),FLAG(144),F(144)
  DIMENSION WAVE(48,3),TAU(48,3)
  INTEGER F
  REAL L
  LOGICAL FLAG
  EQUIVALENCE (FLAG(1),F(1))
  EQUIVALENCE (W(1),WAVE(1,1)),(T(1),TAU(1,1))
  NSP=144
  READ (5,101) (W(K),F(K),(COEF(I,K),I=1,4),K=1,NSP)
101 FORMAT (F6.3,A1,3X,4E12.3)
  DO 20 K=1,NSP
    FLAG(K)=.FALSE.
    IF (F(K).NE.0) FLAG(K)=.TRUE.
  20 CONTINUE
1000 READ (5,102) H2OPCM,X02KM,PRESS,TAUSC
102 FORMAT (4F5.0)
  IF (PRESS.EQ.0.) PRESS=1.
  IF (TAUSC.EQ.0.) TAUSC=1.
  CO2ACM=X02KM*32.
  L(1)=1./H2OPCM
  L(2)=1./SQRT(H2OPCM*PRESS)
  L(3)=1./CO2ACM
  L(4)=1./SQRT(CO2ACM*PRESS)
  DO 10 K=1,NSP
    IF (FLAG(K)) GO TO 14
    DO 12 I=1,4
      12 A(I)=(L(I)*COEF(I,K))**2
      XF=1./SQRT(A(1)+A(2))+1./SQRT(A(3)+A(4))
      GO TO 11
    14 XF=PRESS/COEF(3,K)/L(3)
    11 T(K)=TAUSC*EXP(-XF)*100.
    IF (XF.EQ.0.) T(K)=0.
  10 CONTINUE
  WRITE (6,105)
105 FORMAT (1H1,13X,43HMOLECULAR ABSORPTION OF THE INFRARED IN AIR) ...
  WRITE (6,106) X02KM,H2OPCM
106 FORMAT (1H0,13X,13HPATH LENGTH ,F5.2,4H KM,13X,F5.2,11H PR CM,H
120)
  WRITE (6,108)
108 FORMAT (1H0, 13X,3(16HWAVE- TRANS- ,6X)/
11H ,13X,3(16HLENGTH** MISSION,6X)/
21H ,13X,3(16HMICRONS PERCENT,6X)/1H )
  WRITE (6,109)((WAVE(K,J) ,TAU(K,J),J=1,3),K=1,48)
109 FORMAT ((1H ,13X,3(F6.3 ,2X,F6.1,7X)))
  WRITE (6,110)
110 FORMAT (1H0,13X,63H** WAVELENGTH OF LOCAL MAXIMUM OR MINIMUM OF TR
ANSMISSION CURVE)
  GO TO 1000
END

$DATA
***** INSERT ALL 144 ENTRIES OF TABLE 2 HERE *****
34.5 15. 1. 1.

```

***** SAMPLE OUTPUT *****

MOLECULAR ABSORPTION OF THE INFRARED IN AIR

PATH LENGTH 15.00 KM

34.50 PR CM H2O

WAVE- LENGTH** MICRONS	TRANS- MISSION PERCENT	WAVE- LENGTH** MICRONS	TRAN S- MISSION PERCENT	WAVE- LENGTH** MICRONS	TRANS- MISSION PERCENT
3.000	0.1	3.535	38.9	4.380	0.
3.010	0.1	3.540	23.1	4.450	0.
3.020	0.1	3.550	25.0	4.490	0.4
3.030	0.2	3.555	23.3	4.500	0.0
3.040	0.0	3.560	43.4	4.520	0.0
3.050	0.0	3.570	28.6	4.530	0.0
3.060	0.0	3.580	39.8	4.554	3.5
3.070	0.0	3.585	22.5	4.560	2.7
3.080	0.1	3.600	47.7	4.587	12.7
3.090	0.0	3.615	31.2	4.595	9.6
3.100	0.0	3.625	61.4	4.605	15.5
3.110	0.0	3.635	39.7	4.615	6.2
3.120	0.1	3.645	68.4	4.630	8.3
3.130	0.2	3.650	44.8	4.637	6.0
3.140	0.1	3.655	49.8	4.643	6.8
3.160	2.4	3.670	9.3	4.650	5.9
3.170	1.8	3.700	69.4	4.660	7.9
3.200	0.0	3.710	37.0	4.670	1.5
3.216	0.0	3.720	63.0	4.680	12.9
3.223	0.0	3.730	31.1	4.690	8.7
3.230	0.1	3.745	57.5	4.700	4.2
3.240	0.0	3.755	24.5	4.715	6.8
3.250	0.5	3.770	47.	4.720	2.7
3.260	0.1	3.790	36.	4.730	8.0
3.270	0.6	3.800	70.	4.740	6.2
3.290	0.0	3.810	27.5	4.745	8.5
3.300	0.0	3.820	67.1	4.755	3.3
3.310	0.0	3.830	30.6	4.760	3.8
3.327	2.2	3.840	63.3	4.780	0.3
3.333	0.6	3.860	37.9	4.790	2.3
3.340	0.7	3.870	53.8	4.800	0.1
3.350	0.3	3.880	40.0	4.810	0.0
3.370	4.0	3.910	71.2	4.820	1.0
3.380	4.3	3.930	45.1	4.830	0.0
3.400	15.4	3.940	64.5	4.840	0.2
3.402	6.9	3.950	66.0	4.855	2.2
3.420	35.9	3.960	79.3	4.860	1.5
3.427	31.6	4.000	71.2	4.870	1.5
3.433	31.5	4.050	46.1	4.890	0.0
3.440	25.9	4.060	43.1	4.900	0.0
3.445	37.0	4.100	26.0	4.920	1.2
3.450	26.3	4.140	10.6	4.930	0.5
3.460	41.7	4.150	7.6	4.940	0.0
3.470	37.5	4.160	6.9	4.955	0.
3.490	40.9	4.180	0.7	4.965	0.0
3.500	37.1	4.190	0.	4.975	0.0
3.514	51.6	4.350	0.	4.990	0.0
3.525	41.0	4.377	0.0	5.000	0.0

** WAVELENGTH OF LOCAL MAXIMUM OR MINIMUM OF TRANSMISSION CURVE

UNCLASSIFIED

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